



# **Lunar Crater Observation and Sensing Satellite (LCROSS) Mission: Results from the Visible Camera and the UV/Visible Spectrometer aboard the Shepherd Spacecraft**

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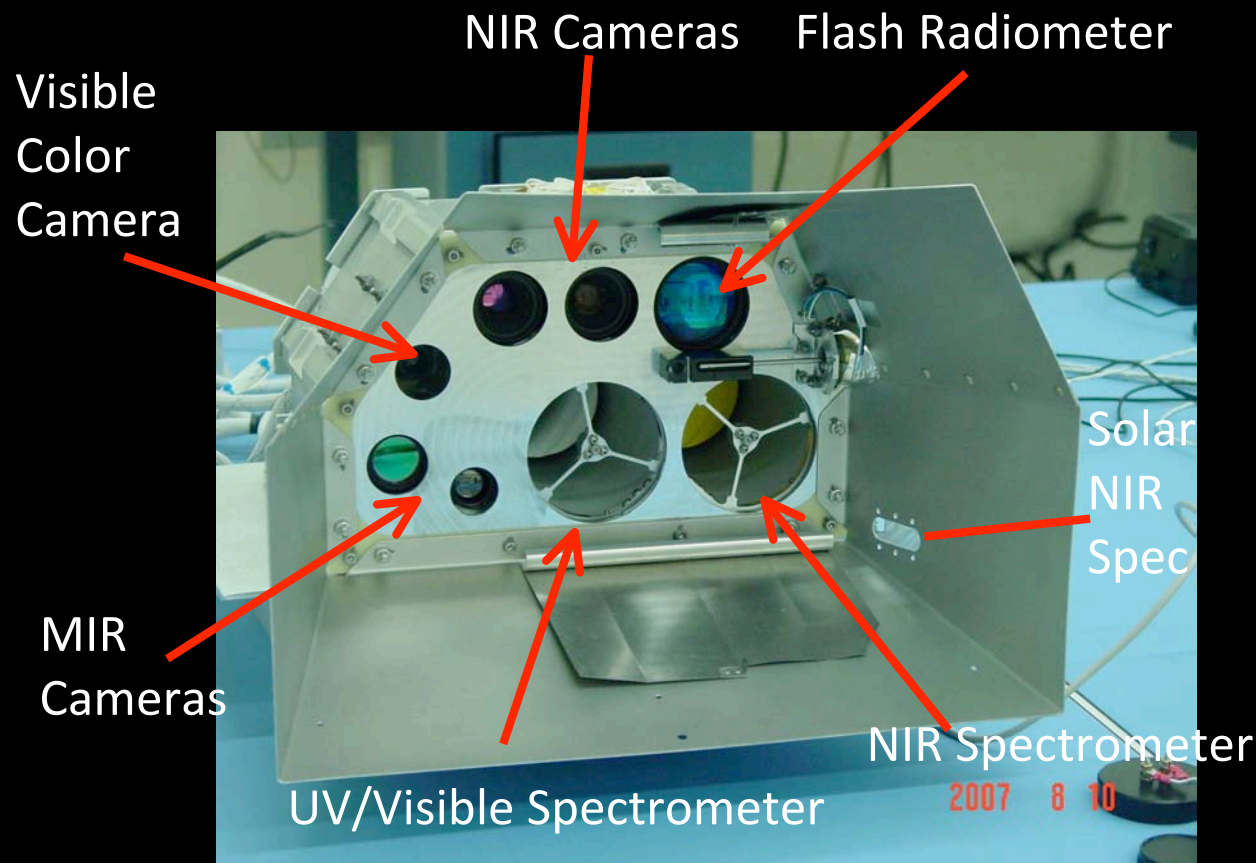
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TX

Lunar Crater  
Observation &  
Sensing Satellite  
(LCROSS)





# Ultraviolet / Visible Spectrometer (VSP)



- VSP provided by Ocean Optics
  - Wavelength range of 260-650 nm
- $\Delta\lambda \sim 0.400 \text{ nm}$

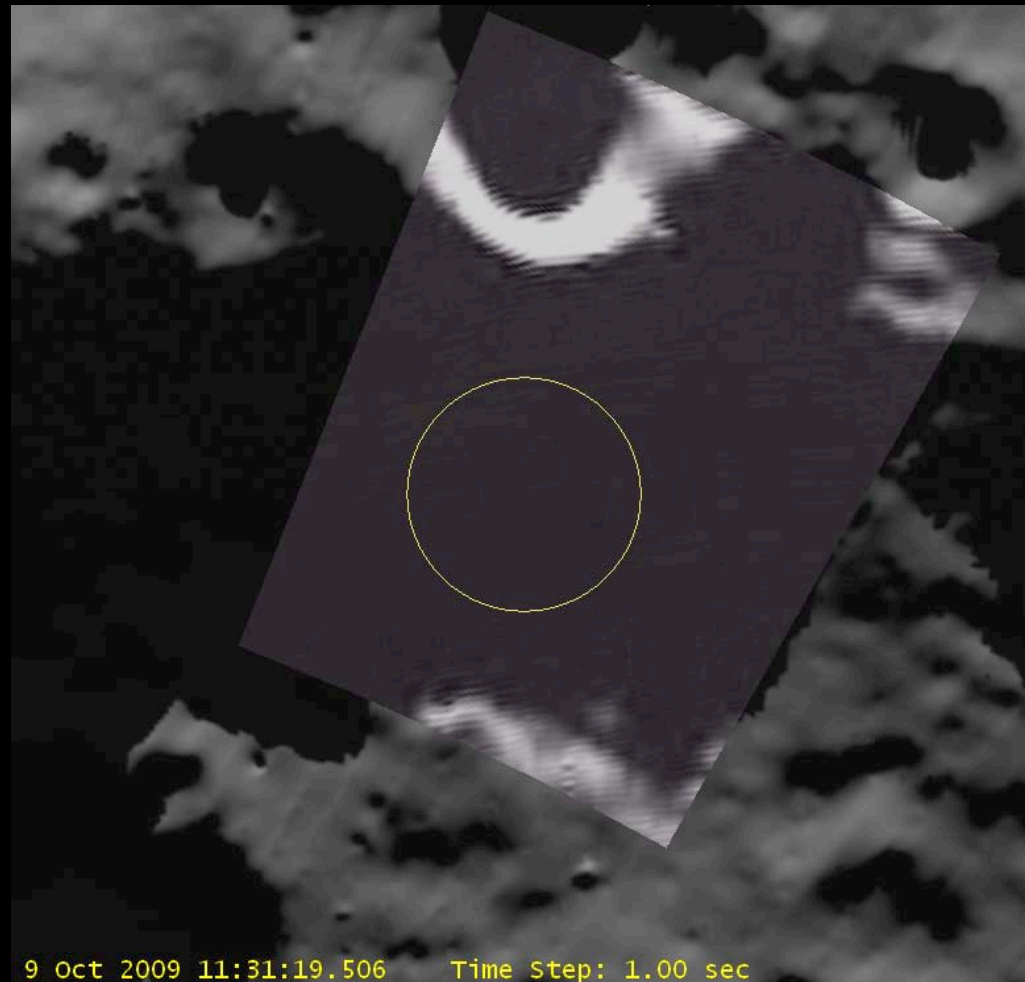
**Payload Observation Deck (POD)**



# UV/Vis Spectrometer FOV



The UV/Visible Spectrometer field of view (FOV) is within permanent shadow at the time of impact.



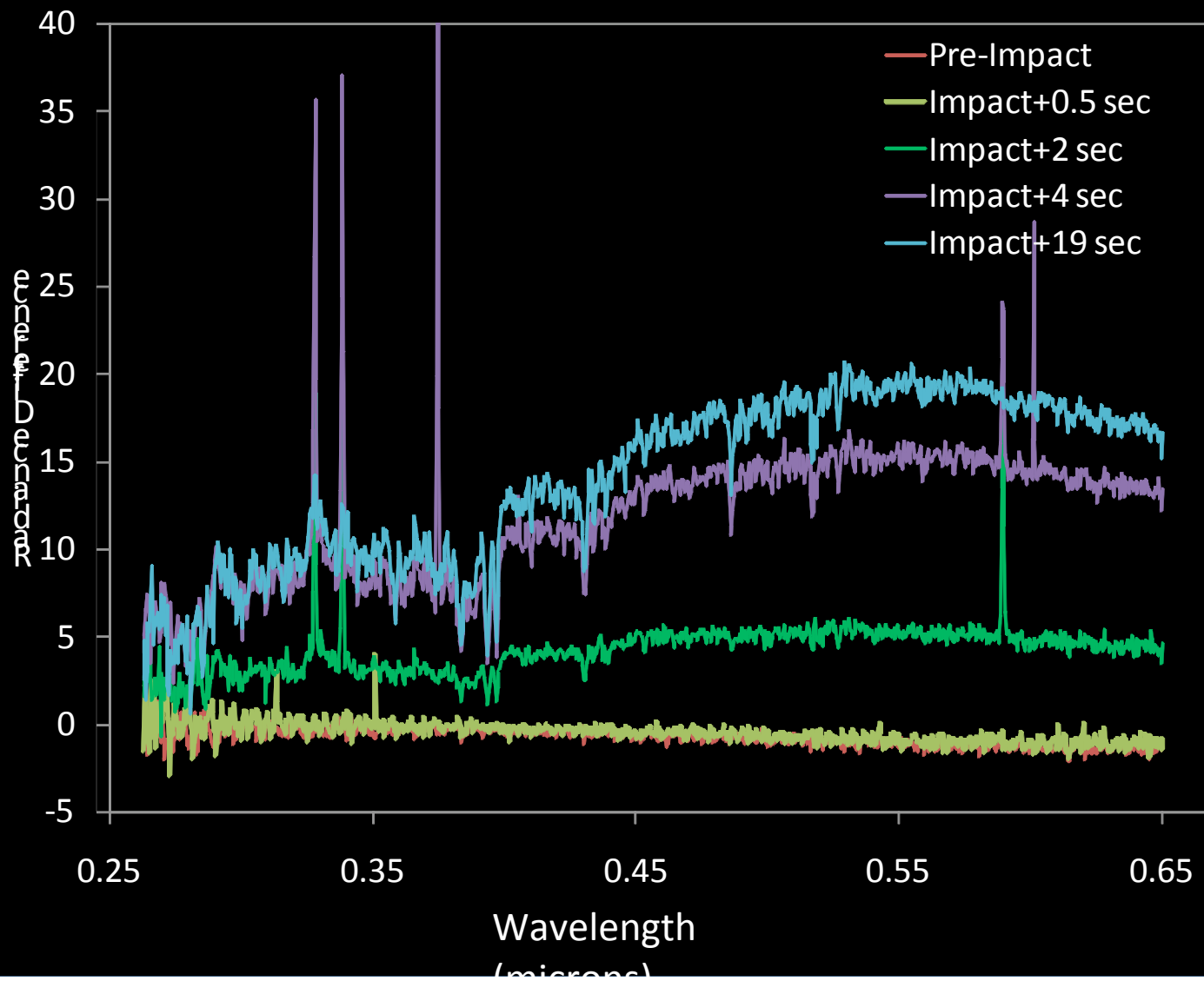
9 Oct 2009 11:31:19.506 Time Step: 1.00 sec



# UV/Visible Spectra

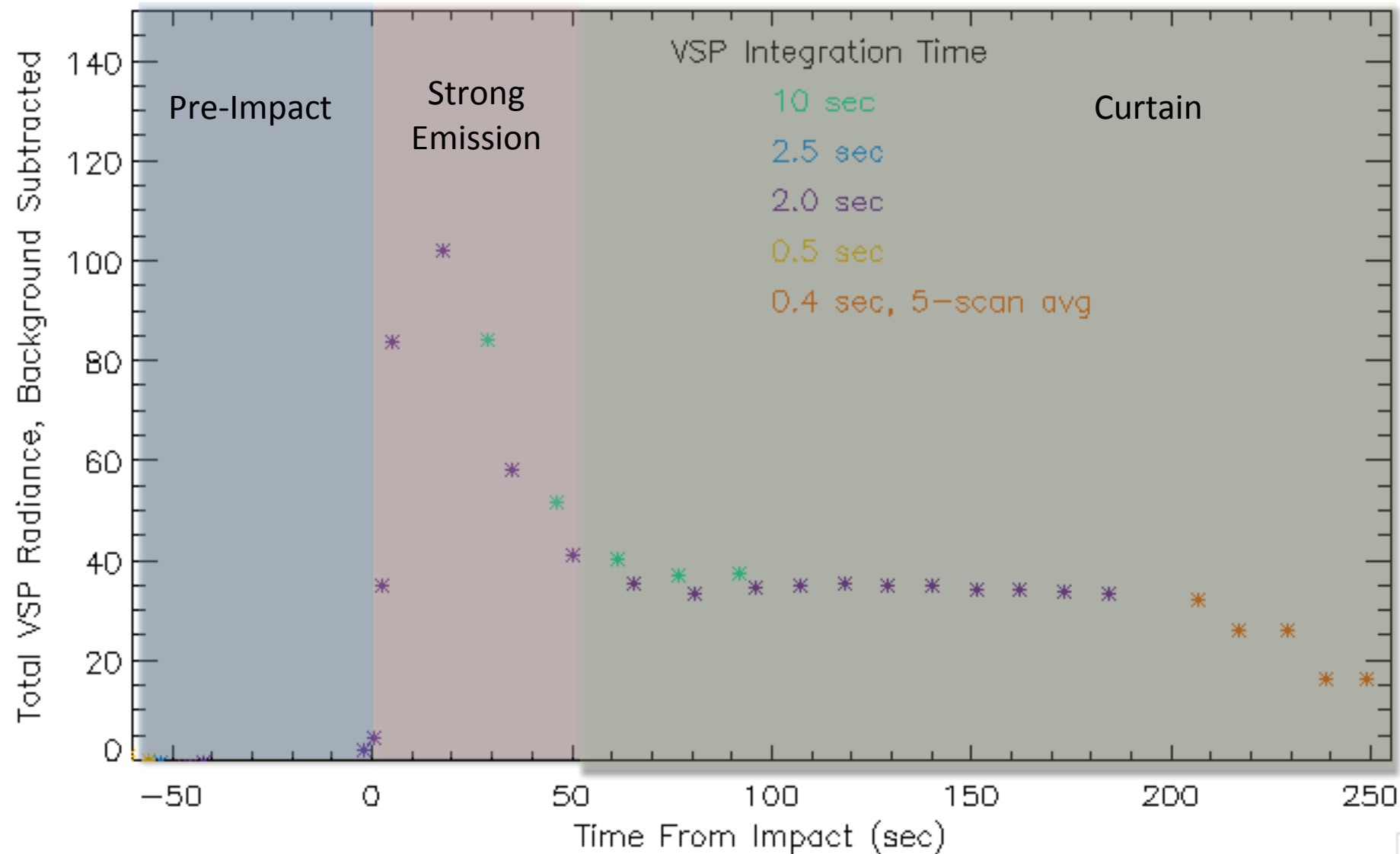


UV/Visible Observations Just After Impact



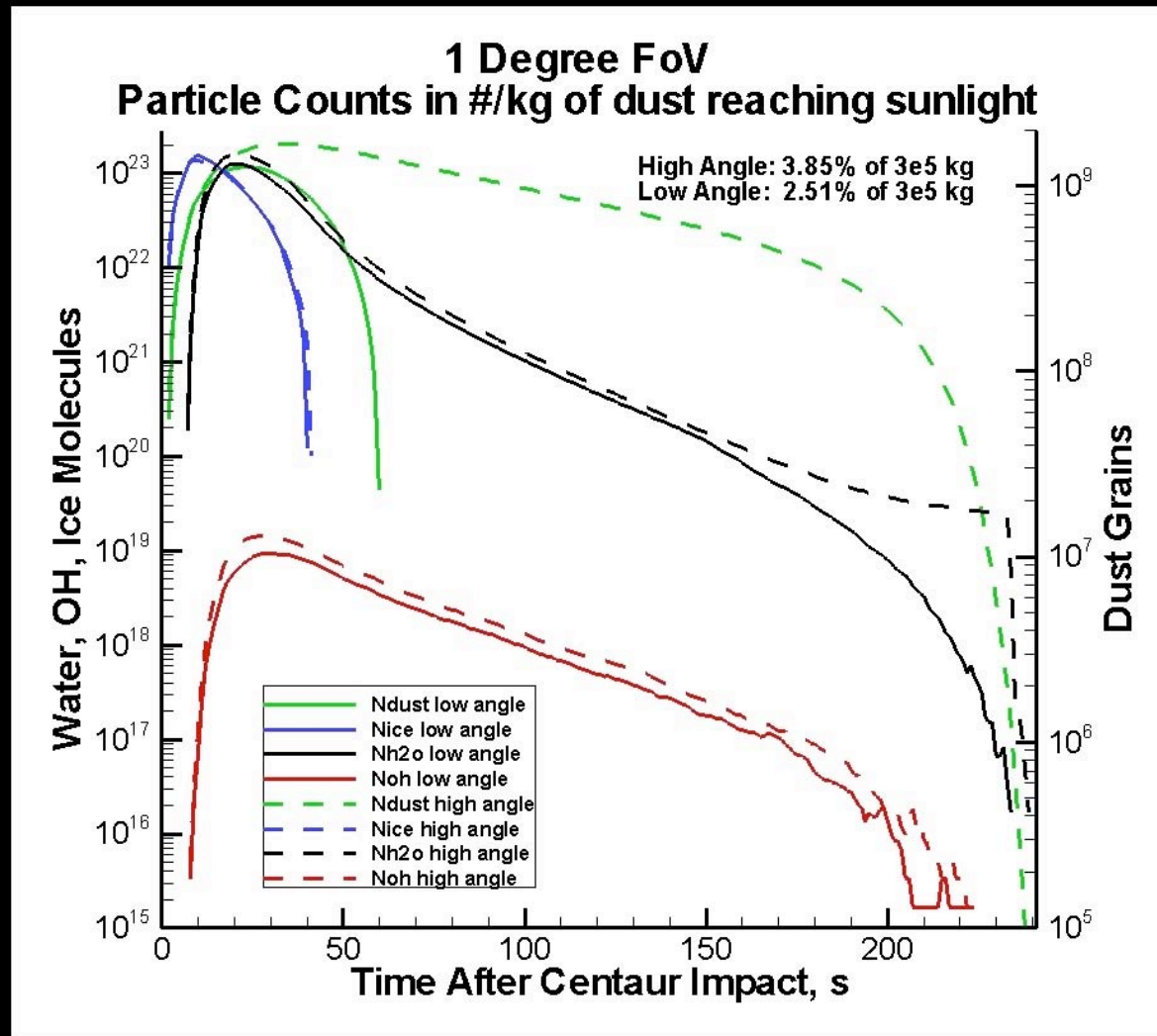


# VSP Light Curve





# High Angle Plume



- VSP observations of scattered sunlight off dust grains for T+200 seconds requires presence of a high angle plume.
- VSP observations best explained by a combination of a low and high angle plume.

From D. Goldstein, D. Summy, U Texas at Austin.



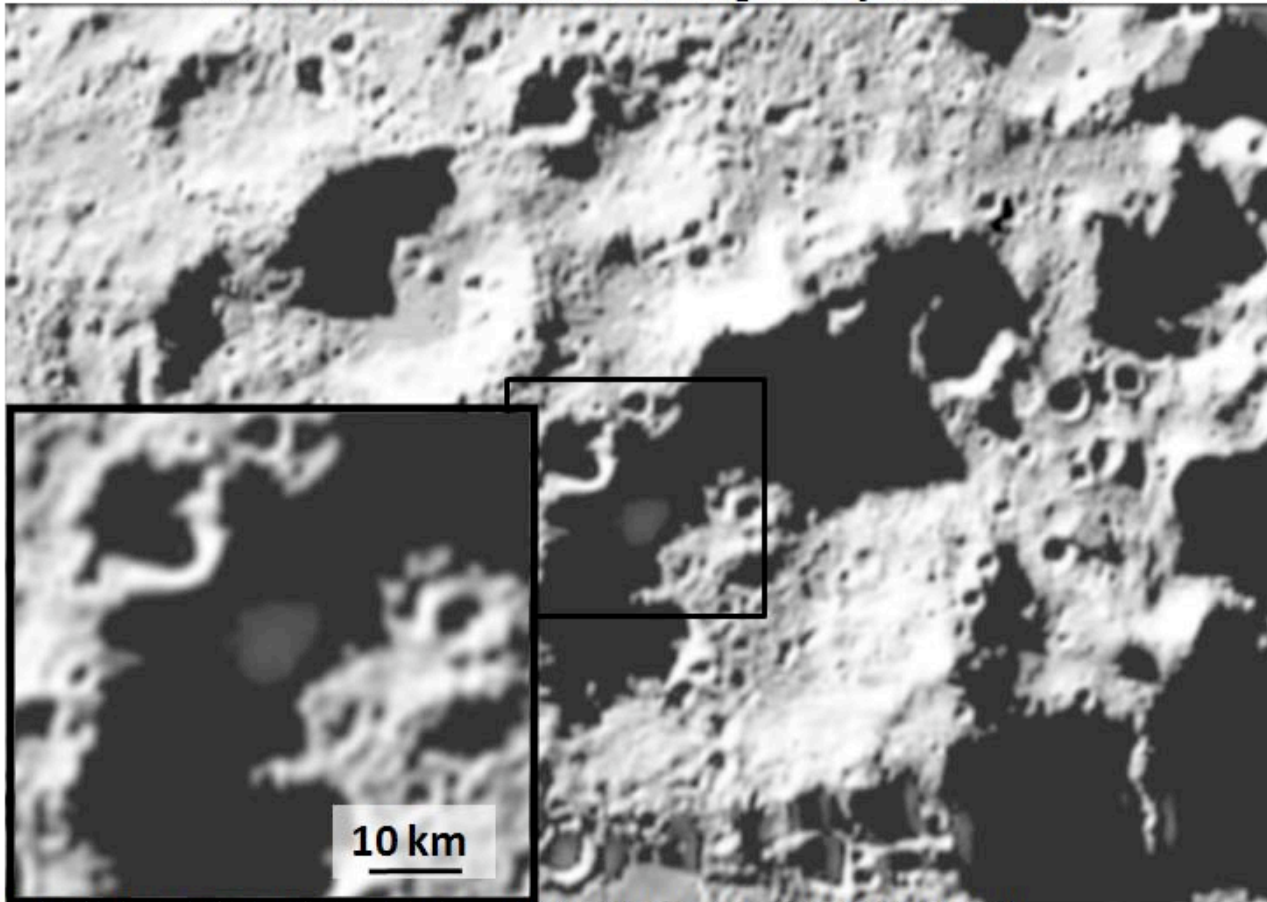


# Visible Camera (VIS)



The ejecta plume is observed in the Visible Camera for ~50 seconds after impact.

LCROSS Visible Camera Image of Ejecta Cloud



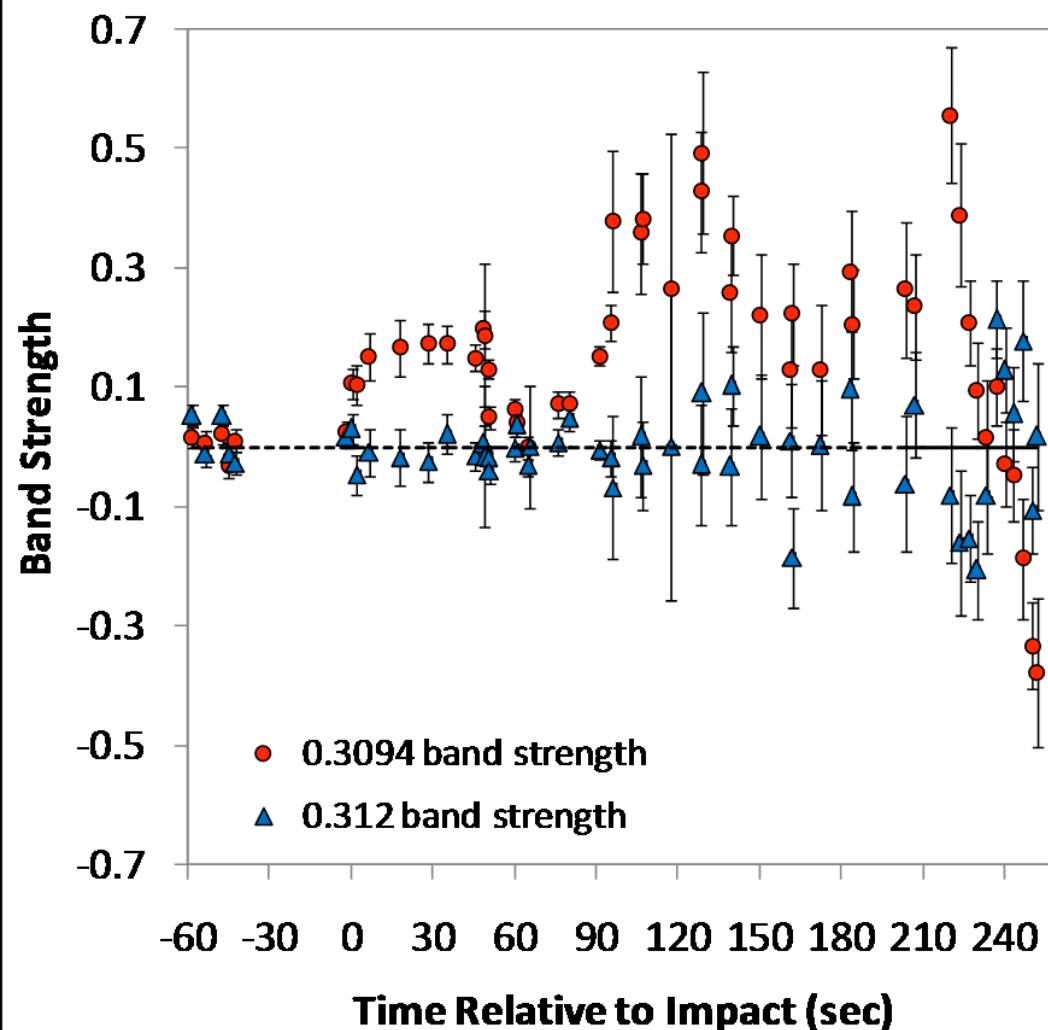
Brightness of plume is high enough from 0-43 seconds to observe in VIS.

VIS observations are consistent with the VSP light curve (0-43 seconds is when the radiance is highest).

LCROSS/NASA ARC B. Hermalyn (Brown University), A. Colaprete (NASA Ames)



# Hydroxyl



Hydroxyl is observed with the UV/Visible spectrometer.

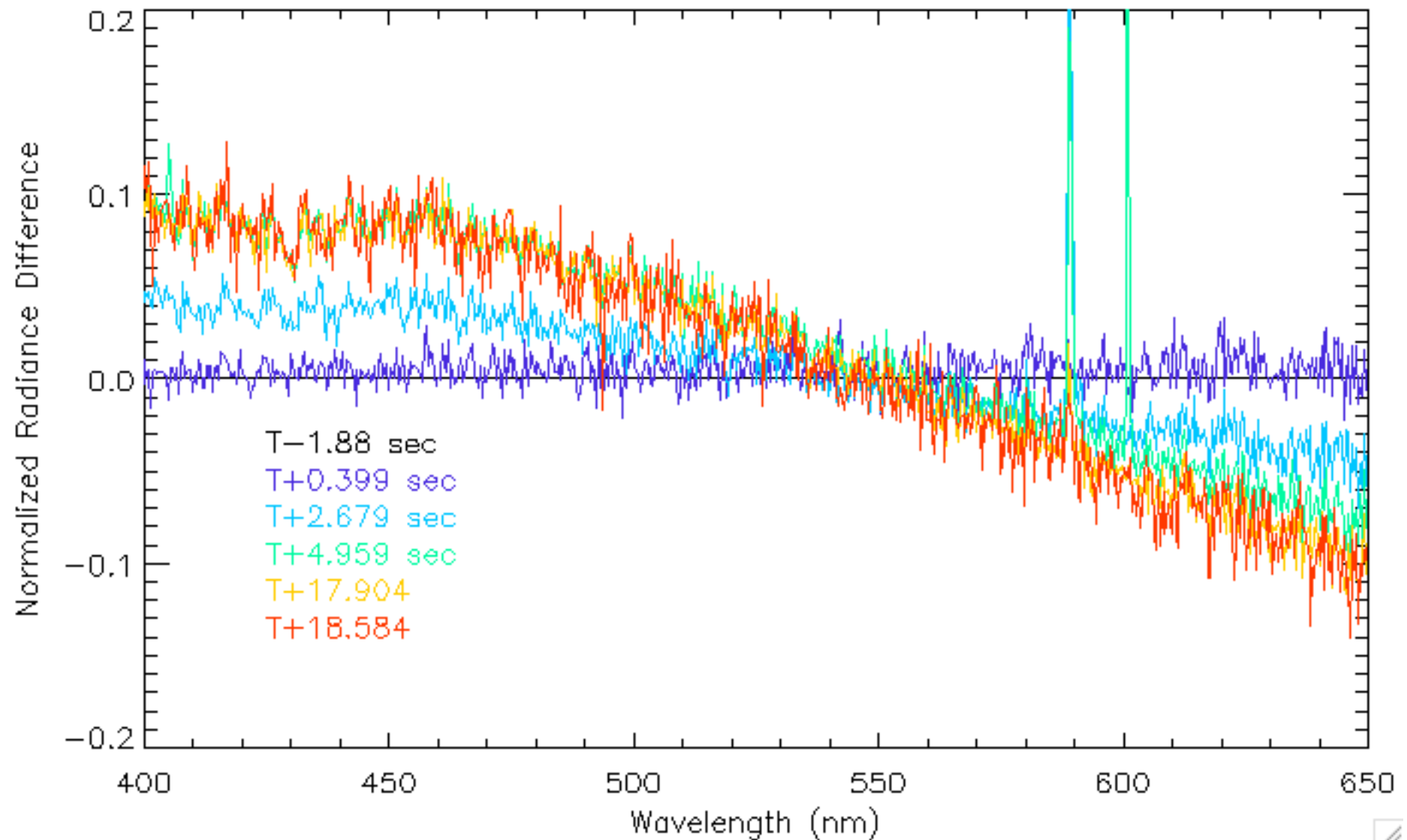
Hydroxyl (first 50 seconds) is produced from ice particles that have sublimated & then photodissociated.

Later hydroxyl (90+ seconds) may be a byproduct of vapor being released over time from the impact site.



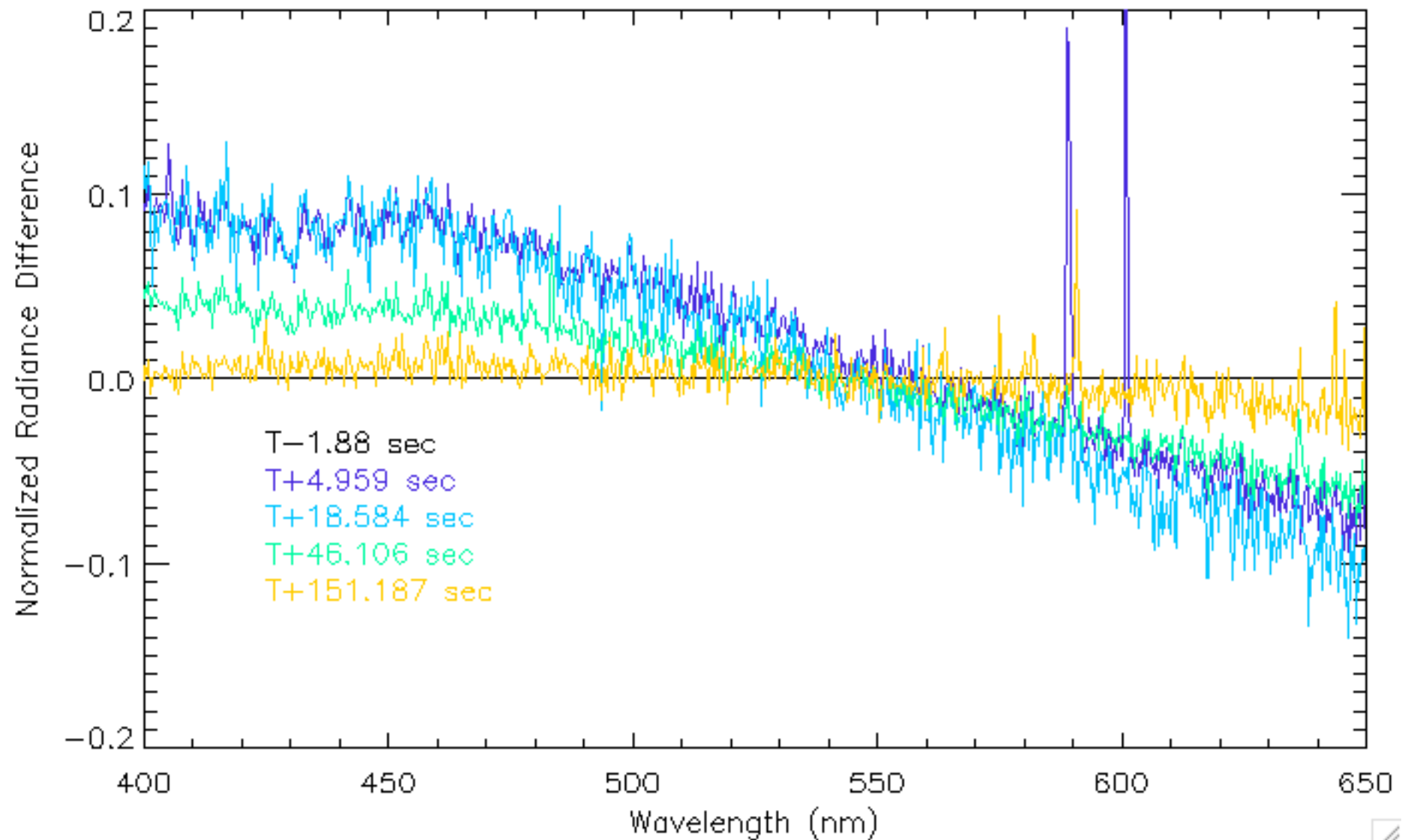


# Color Evolution



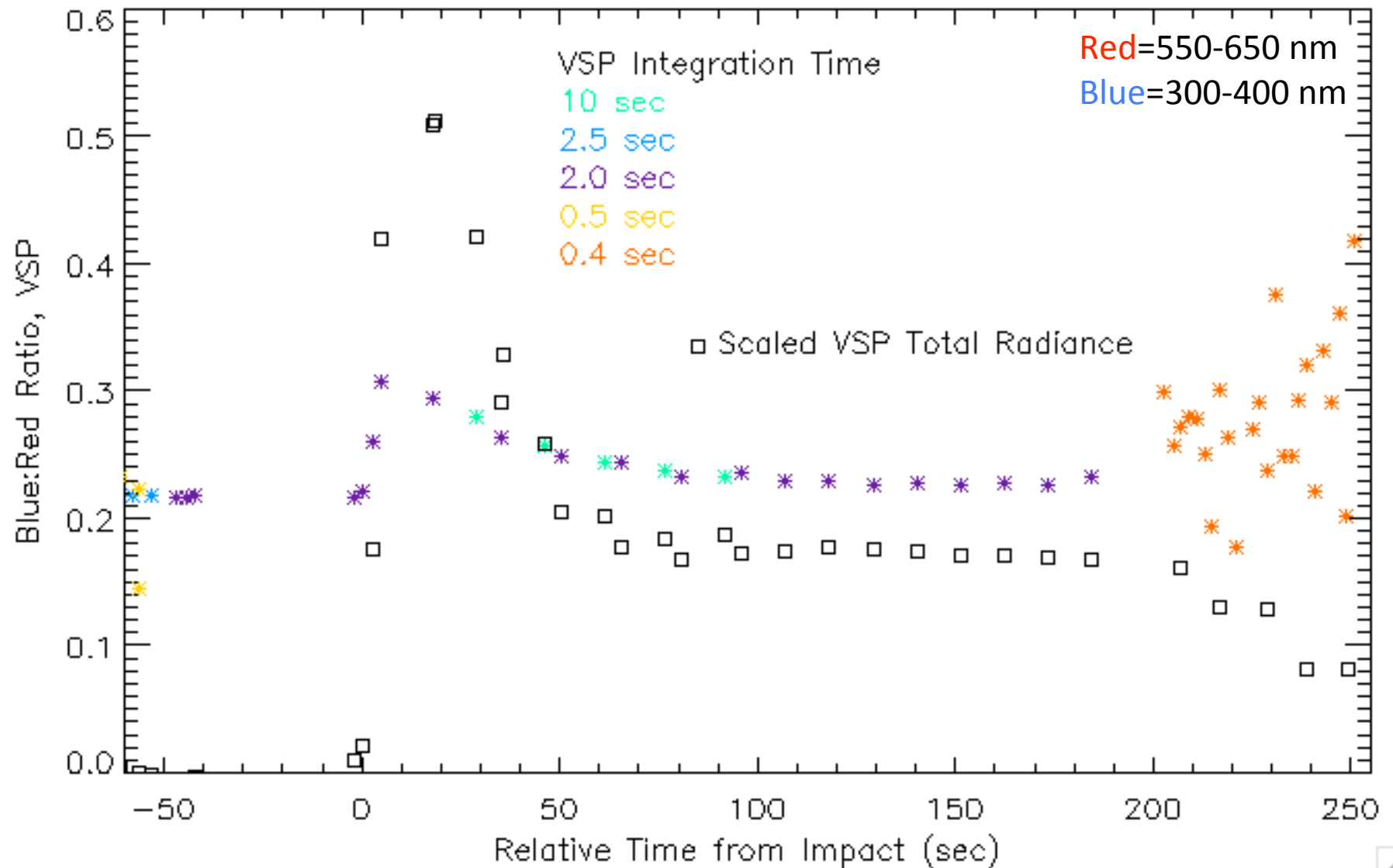


# Color Evolution



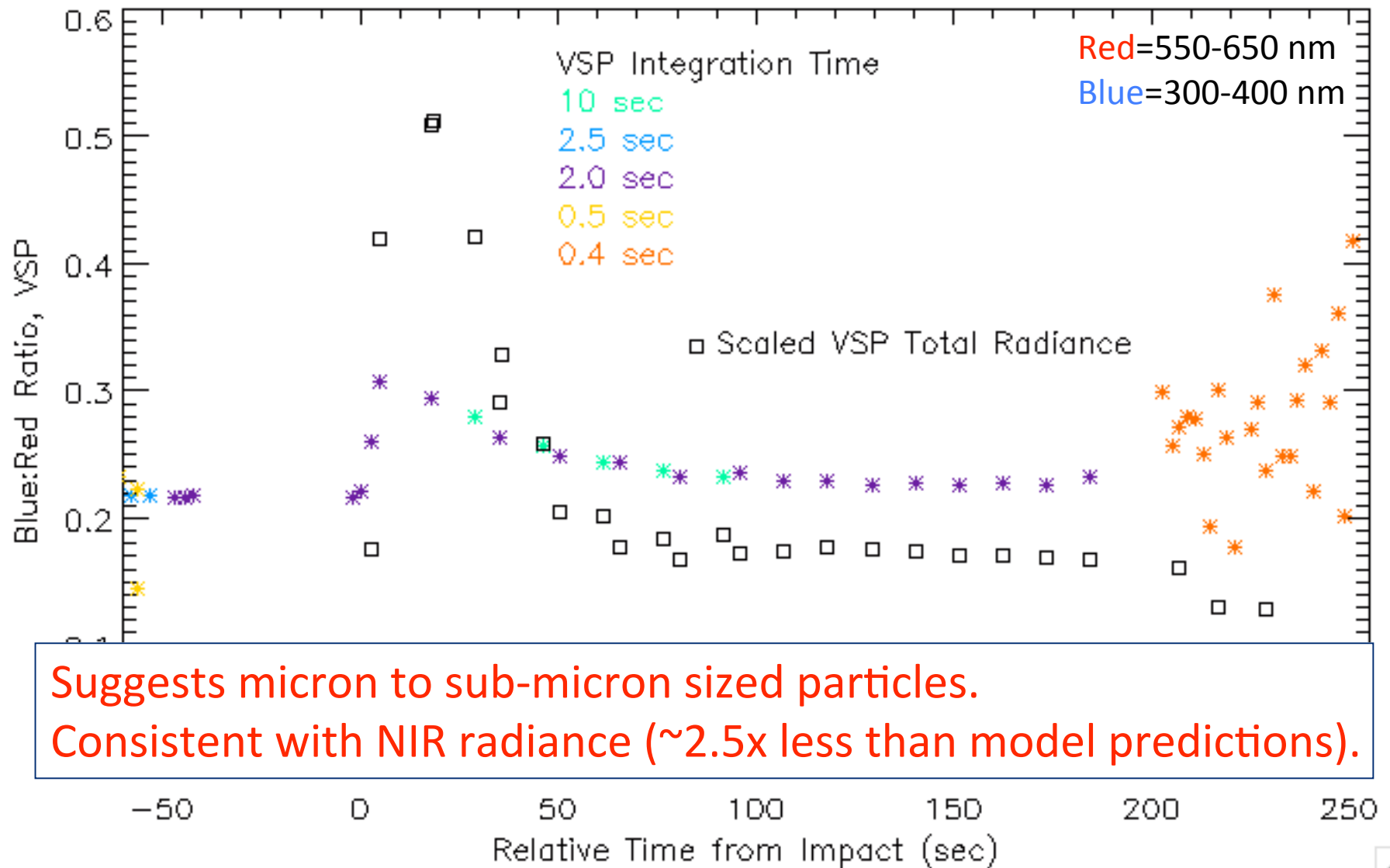


# VSP: Light Curve & Blue:Red Ratio





# VSP: Light Curve & Blue:Red Ratio





# Ballistics Model



An impact plume was modeled and the parameters of the model adjusted to complete a least squares fit on two time series data sets from the VSP spectrometer: the total VSP radiance and the Blue:Red ratio.

FIXED PARAMETERS		FIT PARAMETERS
Density of regolith	3300 kg/m <sup>3</sup>	Mass of Gas
Average spacecraft velocity	2323 m/s	Ice Grain Purity
Spacecraft altitude at Centaur impact	600 km	Temperature of Gas
Altitude of shadow	833 m	Mass lofted into sun*
Absorption of water	100 / m	Power law of particle velocity to radius*
Ice temperature	25 K	Plume angle*
Sublimation temperature	200 K	Water mass in plume *
Molecular mass of gas	18	Extra Fines
Thermal heat capacity of water	4318 J/kg/K	Particle velocity*
Flux at Earth	1400 W/m <sup>2</sup>	
DoF of Gas	18	
Water albedo : regolith albedo	3	* = fitted separately for each plume component





# Additional Observational Constraints

## Observational Constraint

1. Plume ejecta reaches sunlight 1-2 seconds after impact (VSP continuum rise).
2. Most ejecta material is in sunlight 3-5 seconds after impact (VSP continuum levels).
3. Plume filled VSP FOV at 15 seconds post impact when plume was ~9.8 km across.
4. Plume diameter is ~12 km at 20 seconds post impact (VIS camera imagery).
5. VIS and VSP data indicate plume speed of ~420 m/s for a 30 degree ejecta plume, or 295 m/s for a 45 degree ejecta plume in order to disappear from VIS camera images at 42 seconds (Schultz et al. 2010).
6. NIR data suggests ejecta was traveling >200 m/s.
7. Low angle plume mass <2300 kg (Schultz et al. 2010).
8. Ejecta mass into sunlight: 2202 to 4382 kg (Colaprete et al. (2010); 1277-2452 kg (Schultz et al. 2010).
9. The plume remains bright in the VSP for 234 seconds.
10. Water Mass Fraction estimated as 6.5 +/- 2.3% in ejecta (Colaprete et al. 2010).
11. Total water ice mass observed in ejecta plume estimated as ~131 kg at T+25 sec (Colaprete et al. 2010).



# Ballistics Model



Five model components to be turned on/off: High angle plume, low angle plume, velocity power law, ice sublimation, additional fines

	Scenario #	1	2	3	4	5	6	7
1)	High angle Plume	1	1	1	1	1	1	0
2)	Low angle Plume	1	1	1	1	1	0	1
3)	Velocity power law	0	0	0	1	1	0	1
4)	Crushed Fines	0	0	1	0	1	0	0
5)	Sublimation	0	1	0	0	1	1	0
	Normalized Least Squares Fit	10	3	10	8	2.5	3.5	4
	Score (/11)	4	11	4	8	11	9	8



# Ballistics Model



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3)	Velocity power law	0	0	0	1	1	0	1
4)	Crushed Fines	0	0	1	0	1	0	0
5)	Sublimation	0	1	0	0	1	1	0
	Normalized Least Squares Fit	10	3	10	8	2.5	3.5	4
	Score (/11)	4	11	4	8	11	9	8



# Ballistics Model



FIT PARAMETERS	Simple model + sublimation (Scenario 2)		Best fit model (Scenario 5)	
Total mass of ejecta in sunlight (kg)	1573		1413	
Ice grain purity	0.323		0.56	
Plume parameters	Low Angle	High Angle	Low Angle	High Angle
Total dry mass into sunlight (kg)	1150	227	924	231
Power law of particle velocity to radius	N/A	N/A	0.25	0.05
Plume angle (from normal) (°)	49.68	0.56	44.62	0.52
Water mass in plume (scaled to the dry mass)	0.0945	0.015	0.228	0.199
Extra fines (%)	N/A	N/A	0	9.68
Velocity for 3 micron particles (low angle plume) and 1 um particles (high angle plume) [m/s]	500	600	453	600
Plume diameter at 20 sec (m)	15,094	234	12,793	217



# Ballistics Model



Observational Constraint	Model Result (best fit model)
1. Plume ejecta reaches sunlight 1-2 seconds after impact (VSP continuum rise).	Particles traveling at 600 m/s will take 1.4 seconds to travel straight up into sunlight.
2. Most ejecta material is in sunlight 3-5 seconds after impact (VSP continuum levels).	Particles traveling at 400 m/s will take 2.6 seconds to travel straight up into sunlight
3. Plume filled VSP FOV at 15 seconds post impact when plume was ~9.8 km across.	Model predicts plume diameter is 9.6 km at 15 seconds post impact.
4. Plume diameter is ~12 km at 20 seconds post impact (VIS camera imagery).	Model predicts plume diameter is 12.8 km at 20 sec post impact.
5. VIS and VSP data indicate plume speed of ~420 m/s for a 30 degree ejecta plume, or 295 m/s for a 45 degree ejecta plume in order to disappear from VIS camera images at 42 seconds (Schultz et al. 2010).	Model shows low angle plume speed 453 m/s.





# Ballistics Model

Observational Constraint	Model Result (best fit model)
6. NIR data suggests ejecta was traveling >200 m/s.	Model shows plume >400 m/s.
7. Low angle plume mass <2300 kg (Schultz et al. 2010).	Model shows low angle plume mass <1500 kg.
8. Ejecta mass into sunlight: 2202 to 4382 kg (Colaprete et al. (2010); 1277-2452 kg (Schultz et al. 2010).	Model predicts 1414 kg.
9. The plume remains bright in the VSP for 234 seconds.	Model predicts brightness goes to zero at 228 s.
10. Water Mass Fraction estimated as 6.5 +/- 2.3% in ejecta (Colaprete et al. 2010).	Model predicts 10%.
11. Total water ice mass observed in ejecta plume estimated as ~131 kg at T+25 sec (Colaprete et al. 2010).	Model predicts 142 kg.



# Plume Evolution

## Phase 1 (T = 0-10 seconds)

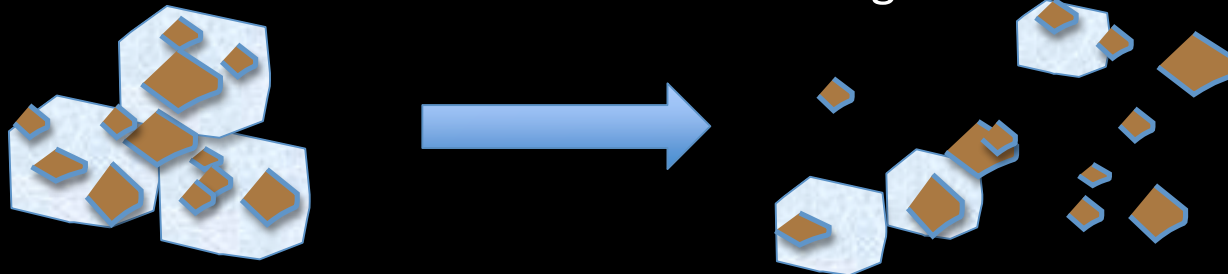
Blue:Red increase → particles becoming smaller.

- decrease in ice grain size due to sublimation and/or the break up of loosely consolidated grains held together by volatiles.
- further supported by observations of OH, plus near-infrared spectra indicating water ice (Colaprete et al. 2010).

Rapid blueing suggests sublimation of some ice grains occurred quickly.

- rapid sublimation requires presence of impurities within the ice grain

(Beers et al. 2009) → suggests at least some of the ice within Cabeus Crater is comingled with lunar regolith, possibly similar in form to terrestrial ice-cemented ground.





# Plume Evolution



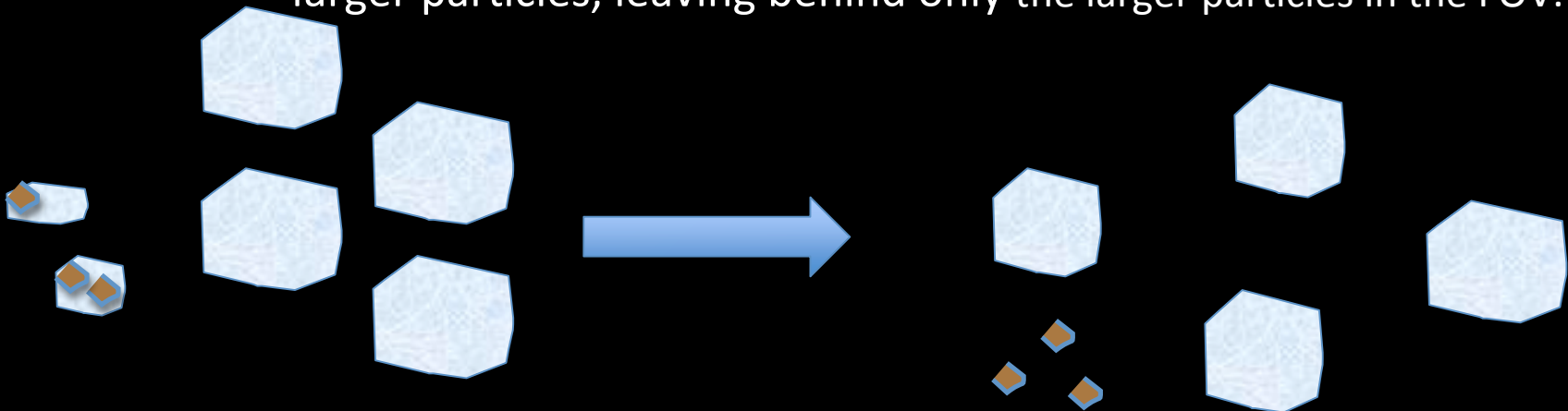
## Phase 2 (T = 10-50 seconds)

Blue:Red ratio is declining. Possible interpretations:

- non-pure ice grains subliming away and thus eventually disappearing, leaving the larger non-sublimed more pure ices behind.

Not strongly supported by modeling

- low angle plume has a smaller average grain size and these particles are no longer seen as they leave the VSP FOV
- power law velocity distribution of particles as a function of their size, so smaller particles travel faster & leave the FOV quicker than the larger particles, leaving behind only the larger particles in the FOV.





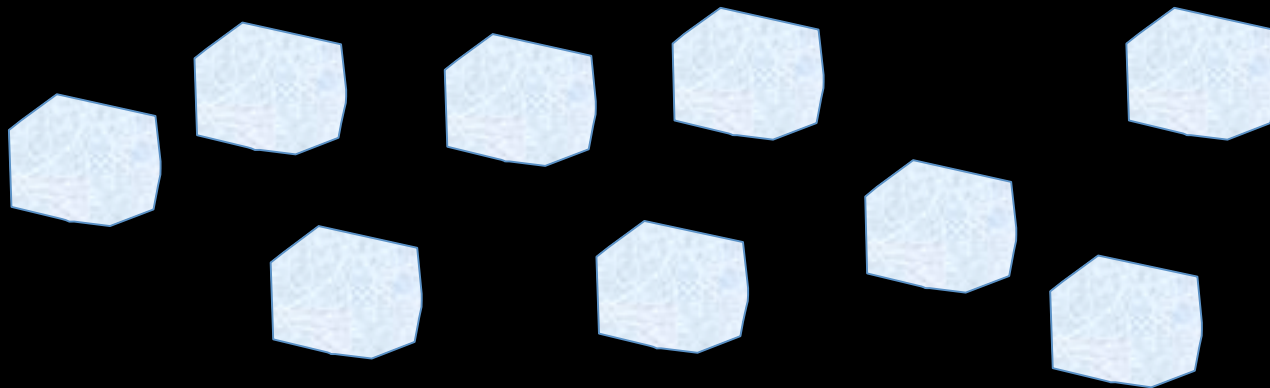
# Plume Evolution



## Phase 3 (T = 50-200 seconds)

Blue:Red ratio remains constant → mean particle size not changing significantly.

- Low angle plume has mostly left the FOV.
- High angle plume continues to disperse & evolve but doesn't leave the FOV.
- Icy particles containing the highest fraction of particulates have already sublimated away (Beers et al. 1999), leaving behind the more pure ice grains. Purer ice takes longer to sublime with respect to dirtier ice grains, and thus this slow rate of change does not dramatically alter the overall particle size, resulting in a relatively constant Blue:Red ratio in this time period.





# Plume Evolution

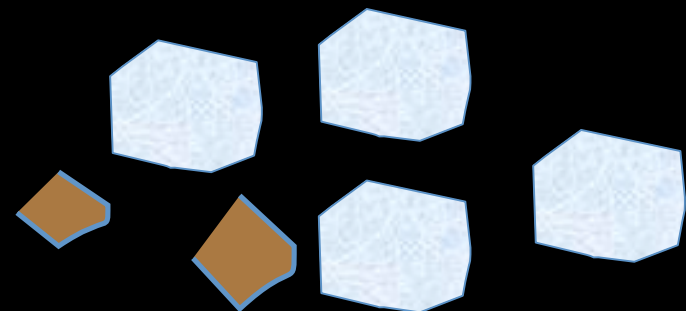
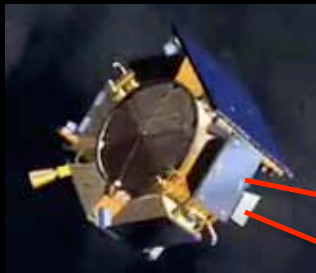


## Phase 4 (T = 200-250 seconds)

Blue:Red ratio again begins to increase (decrease in red, blue remains constant).

The light curve shows that the radiance values are also decreasing.

- 3 micron particles can be responsible for this type of spectral response.
- sublimation of relatively pure ice grains which have now had enough time to lose sufficient mass in which to decrease their particle size.
- Shepherding Spacecraft is flying through the remaining impact cloud, so the rapidly changing field of view also contributes to decrease in radiance (S-S/C targeted ~2.5 km from Centaur impact location).







# Summary



- Lofted dust grains remained suspended above the lunar surface for the entire 250 seconds of observation after impact.
- The impact plume was composed of both a high angle and low angle plume component.
- The high angle plume was 0.5-1 degree from normal with particles traveling at  $\sim 600$  m/s while the low angle plume had an angle of 40-50 degrees and a speed of 450-500 m/s.
- Dust particle sizes lofted above the lunar surface were micron to sub-micron in size.
- Water ice particles of varying purity were also contained within the ejecta cloud and simultaneously photo-dissociated and sublimated after reaching sunlight.



Questions